

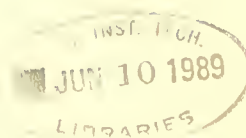
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THE DYNAMICS OF R&D COMMUNITIES:
IMPLICATIONS FOR TECHNOLOGY STRATEGY

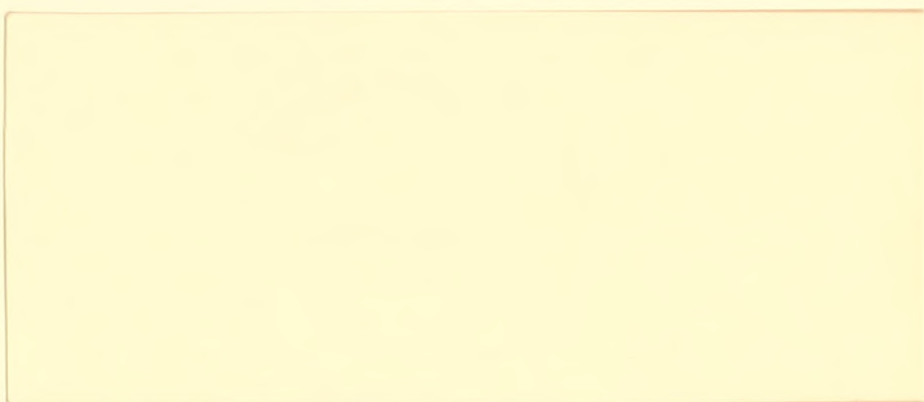
by

Michael A. Rappa

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**THE DYNAMICS OF R&D COMMUNITIES:
IMPLICATIONS FOR TECHNOLOGY STRATEGY**

by

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Presented at the CORS/TIMS/ORSA Conference
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INTRODUCTION

A central task of the research laboratory manager is to determine the optimal allocation of scarce resources among a variety of technologies that could be developed by the research staff. It is a difficult and unrelenting challenge with no clear answers and with the options changing over time. Whether it is a promising new technology on the horizon or a technology currently in development that is proving less promising than initially thought, the laboratory's portfolio of projects is subject to frequent review and reconsideration.

In what directions should a research laboratory expend its effort? What new technologies should be vigorously pursued, and what existing projects should be curtailed? In sorting through these questions, the laboratory manager must assess each technology's potential impact on current business, its risks, its return, and estimate the length of time it might take to reach the marketplace--all with an eye toward what might be done by competitors. The time frame or window for a technology is particularly critical to the assessment. Even though the potential of a technology may seem significant, its importance will increase or diminish depending upon the length of time it will take to develop.

There is no easy formula for estimating a technology's window. Over the past several decades the effort to develop the field of technological forecasting has yielded a limited number of approaches, but even so most firms continue to rely heavily on expert judgement.¹ The benefits and limitations of expert judgement are fairly well understood: in short, experts in a given technology are the most knowledgeable to judge it, but they are more likely to overestimate its potential and

¹ See for example, Fusfeld and Spital, "Technology Forecasting and Planning in the Corporate Environment," 1980, and Martin and Irvine, *Foresight in Science*, 1985.

underestimate the degree of difficulty in bringing it to fruition.² Moreover, it is not unusual to find that for every optimistic opinion an equally pessimistic one can be found. Given that resources are limited, the determination over the worthiness of developing a particular technology may place a laboratory's researchers at odds with one another and the resulting debate can reach an impasse. This can make laboratory life interesting for one who enjoys hearty exchanges, but it is no solace for the manager who needs to take action and make effective allocation decisions. Indeed, the entire laboratory atmosphere can become strained, when researchers become impatient with the slowness in approving new projects and managers become impatient waiting for investments in ongoing projects to yield tangible products or processes.

The discovery of superconductivity at high temperatures in bulk ceramic materials (namely, the compound of lanthanum-barium-copper-oxide) in 1986 serves as a excellent example of the challenge posed by an emerging technology.³ The event, which occurred at the IBM research laboratory in Zurich, Switzerland by two scientists who later were awarded a Nobel Prize for their effort, is considered today to be extremely significant in terms of both its scientific and technological implications and indeed, some believe on the same scale as the discovery of the transistor effect in semiconductor material at Bell Laboratories forty years ago. Like the transistor, it could ultimately lead to vast improvements in areas such as high-speed computing. However, the realization of a computer with components based upon the new superconducting material is not a trivial task nor is it certain whether it could be achieved--let alone when. Several problems will have to be addressed, such as, refining the crystalline structure of the material, improving its electrical characteristics, fabricating it into useful devices and circuits in high volume, packaging the components, integrating these components into the other parts of the system, and resolving the scientific question of why the materials behave as they do.

²See Anderson, *Long-Range Forecasting*, Chapter 6, for a discussion of judgmental methods. Also see Luukkonen-Gronow, "Scientific Research Evaluation," 1987, for a review of qualitative and quantitative methods.

³See Muller and Bednorz, "The Discovery of High-Temperature Superconductors," 1987, and Foner and Orlando, "Superconductors: The Long Road Ahead," 1988.

The anticipated speed in overcoming the obstacles facing the application of superconducting ceramics can make all the difference in deciding the proper allocation of a laboratory's resources over time. Yet judgments about the probable time frame for the technology's development are vague at best and opinions are often divided. Initially, rapid progress leading to even more important superconducting ceramic compounds (yttrium-barium-copper-oxide, in particular) generated widespread enthusiasm for near term commercialization of the technology. However, the reality of what lies ahead now has given rise to a more sober opinion among some researchers about the long term nature of the effort. The perils of this situation are readily apparent to the laboratory manager: if one accepts the opinion that such a computer can be realized within five years, the appropriate allocation of resources will be substantially different than if one holds the opinion that such a computer can be realized only within fifteen years. Ironically, it was the same firm, IBM, which beginning in the early 1970's attempted to develop a superconducting computer (using niobium alloys), but had to scale back its effort in 1983 after reportedly spending as much as one-hundred million dollars without success.⁴

The case of superconducting ceramics is not unique. In the past, managers have wrestled with similar decisions and they will continue to do so in the future.⁵ Time and again, they must grapple with the laboratory's research agenda, seeking to understand what new technologies are gaining momentum and what ones are grinding to a halt at the researcher's bench.

The purpose of this study is to assist the research laboratory manager in understanding the rate of progress in the development of technology in order to improve their effort to optimize resource allocation. Specifically, a theoretical model is proposed for assessing the developmental rate of an emerging technology. The model focuses on the community of researchers that coalesces around a

⁴See Robinson, "IBM Drops Superconducting Computer Project," 1983.

⁵Recent claims regarding "cold fusion," if verified, may hold a similar challenge as that of high-temperature superconductors. See Pool, "Fusion Breakthrough?" 1989.

technology: that is, the scientists and engineers who are committed to solving an interrelated set of scientific and technical problems, and who may be organizationally and geographically dispersed, but who nevertheless communicate with each other. The model seeks to uncover the relationship between the structural and behavioral dynamics of this "R&D community" and its rate of progress in solving the myriad of problems it faces. The theory supports the contention that certain changes in the structural and behavioral characteristics of the community may be related to the acceleration or deceleration of a technology's progress toward commercial introduction.

R&D COMMUNITIES

In his influential work *The Limits of Organization*, Kenneth Arrow states that "...organizations are a means of achieving the benefits of collective action in situations where in which the price system fails." Following in a similar vein, it may be that R&D communities are a means of collective action in situations in which the firm (or managerial hierarchy) fails. Given this perspective, it may be helpful to view such communities as efficient meta-organizational structures for accomplishing certain goals reasonably beyond the reach of the individual researcher or team.

Despite the fact that the research community is a familiar concept in the context of the scientific world, its place in the realm of technological development is largely ambiguous.⁶ It is well understood that scientists (particularly those employed in university or government) are members of communities, the so-called invisible colleges, in which information flows with relative freedom between laboratories. These communities provide the mechanism by which members mete out recognition and rewards and set the direction for future research. In contrast, technological development is typically seen as the domain of engineers and the

⁶The historian Edward Constant, whose study of the development of the turbojet elucidates the role of the technological community, states: "While extensive research has been done on 'invisible colleges,' research fronts, and the community structure of science, there has been little analogous sociological or historical investigation of technological practice." (Constant, 1980, p. 8.) For earlier studies of scientific communities see Griffith and Mullins (1972) and Mullins (1972).

industrial firms that employ them. Firms operate to establish proprietary know-how, which then can be leveraged to develop new products or processes that surpass those of competitors. Secrecy, competition, and managerial direction are the *sine qua non* of the technological landscape. Given this traditional conceptualization of technological development, it appears that the notion of a community of researchers is at once incongruent.

A closer examination of science and technology yields exceptions to such broad stereotypes. To view scientific communities as friendly clubs in which members freely share their ideas is misleading. Community members are not immune to fierce competition, racing to stake intellectual claims (typically in the form of journal articles, but increasingly in the form of patents⁷) and, even though it may be contrary to established scientific norms, acting to restrict the flow of information about their research.

Likewise, the world of technology is equally as complex. Firms compete, but they also cooperate with each other, allowing technical information to flow among engineers in different organizations.⁸ Some engineers attend conferences, present technical papers, and publish the results of their work in peer-review journals sponsored by professional societies. Like scientists, they too, may see themselves as members of a particular R&D community, which extends beyond the boundary of their firm. Indeed, some are scientists, in that they are trained in the scientific method and may have doctoral degrees. To the extent that researchers in a particular technological domain consider themselves members of a R&D community, this community may play an instrumental role in influencing the rate and direction of the technology's development. Contrary to established opinion, the development of a new technology may not simply the activity of a handful of

⁷Although it is not new, major research universities, such as MIT and Stanford, are paying increased attention to opportunities to patent the inventions of faculty. MIT has a well-organized staff of professionals dedicated to patenting and licensing activities. See Eberlein (1989) for a description of technology patenting and licensing activities at MIT. The importance of patenting is illustrated in the case of cold fusion research with MIT's recent announcement (via press conference) that it applied for patents on a theoretical explanation of cold fusion, just one day after the theory was formulated (see "Fusion in a Bottle," 1989).

⁸The flow of information among firms is documented in the work of Allen (1979), and recently has received attention from von Hippel (1987) in his examination of know-how trading.

engineers, or of a firm, but instead many individuals working in numerous organizations spread throughout the world.⁹

In the context of this study, the R&D community is defined to include individuals in any type of organization, such as universities, private firms, new ventures, quasi-public corporations, and government research institutes, and furthermore, the community can be global in scope. This concept of a R&D community is obviously more inclusive than that of an industry, but even more so in that it includes firms with no regard to what industry they may be typically classified (for example, semiconductors, computers, chemicals, or aerospace) or no matter what segment they may operate in (such as with the semiconductor industry, there are segments dedicated to materials, devices, process equipment, and so forth), so long as they are focusing on some part of the relevant set of problems. Thus, the community is defined by the problem set and not necessarily by the output, as is normally the case with an industry definition.

THEORETICAL CONSIDERATIONS

In reality, technological development is a vastly complex process. But for this purpose it will be treated as a simplified theoretical abstraction. It is readily admitted that the theory does not adequately describe all of the subtleness of technological development as it might actually occur. However, the intent is to capture the essence of the process such that a basic understanding of the rate of a technology's development can be established.

The foundation of the model rests on the principle that technological development is an intellectual process whereby knowledge is created and applied to form new products or processes. The creation and application of knowledge entails

⁹The notion of a R&D community has been obscured by the tendency to view technological development in terms of inventors and their inventions, such as with the Shockley, Bardeen and Brattain and the transistor. However, a careful historical account shows "It is...unrealistic to see the transistor as a product of three men, or of one laboratory, or of Physics, or even of the forties. Rather its invention required the contributions of hundreds of scientists, working in many different places, in many different fields over many years." (Braun and Macdonald, 1982, p. 43).

resolving certain problems which stand in the way of realizing the desired outcome.¹⁰ The central actors are the individual researchers who become committed to solving the problems, and it is they who set the process in motion. The basic elements of the model are outlined below.

(1) Let the body of knowledge in a given realm of technology be represented as K . Given the state of the world at the time of the technology's initiation, the body of knowledge is projected as an increasing function over the interval of t $(0, \infty)$ represented as $K(t)$ in Figure 1(a). Assume that K can be decomposed into its constituent parts represented as k , which are homogeneous units of knowledge, where $K = \sum k$.

(2) Given $K(t)$, let the level of problems to be resolved (P) be an inversely proportional function decreasing over the interval t $(0, \infty)$, represented as $P(t)$ in Figure 1(b). Assume that P also can be decomposed into its constituent parts, which are homogeneous units of problems, where $P = \sum p$. The relationship between the state of knowledge and the level of problems to be solved is given as $P(t) = u/K(t)$, where u is constant.

At time ($t = 1$), given the assumptions about $K(t)$ and $P(t)$, a projection can be made based on expectations about the future point in time of commercialization (t_c), where the level of knowledge attained (K_c) is sufficient to reduce the problems to a level (P_c) necessary to apply the technology to practice. Notice that it is not assumed all problems will be resolved, and, indeed, the problem solving activity continues after the technology's initial market entry. Furthermore, $P(t)$ is asymptotic to the x- and y-axis, implying that at the initial stage ($t \rightarrow 0$), P is not ascertainable, and that as even as time progresses into the future ($t \rightarrow \infty$), some problems will never be satisfactorily resolved--it is the latter which gives rise to new technologies. It is also important to note that even given the initial assumptions about $K(t)$ and $P(t)$, the probability of finding a solution to each

¹⁰The idea that technology is essentially knowledge has gained acceptance among scholars in several disciplines. For example, see Arrow (1962), Layton (1974), Constant (1980), and Aitken (1985). The work of Katz and Allen (1985) focuses on technology development as an information processing and problem-solving activity. The intent here is to link the concepts of information, knowledge, and problem-solving into a unified model of technological development.

problem is uncertain.¹¹ Lastly, $P_s (= P_t - P_c)$ over the interval $(t > c)$, will be referred to as the problem set: a relatively large value of P_s implies a technology which is a radical departure from the established base of knowledge to reach t_c . In contrast, a relatively small value of P_s implies a technology which is incremental in nature; that is, it is more an extension than a departure from existing base of knowledge.

(3) Let $R_1 (= \sum r)$ represent the community of researchers who attempt to create and apply knowledge in order to resolve the problems facing the technology at time t . Assume they are rational, in the economic sense that they are motivated by self-interest. The researcher conducts two basic activities: (a) the production and communication of information, and (b) the transformation of information into the knowledge required to solve problems. Information production implies the creation of new data through observation and experiment. Communication of information implies that the researcher can also gather information produced by another researcher, and disseminate to others the information he produces. Knowledge is a distinct entity from information in that knowledge enables the researcher to do something (know-how) or explain something (know-why). Having information does not necessarily imply either; the researcher first must make sense of the information available to him in order to solve problems.¹²

The information production, communication and transformation processes are time consuming; therefore, any individual researcher can only accomplish a certain level of effort in a given period of time. Assume that in a single period of time, the amount of information generated by a single researcher (r) is i , and that he can perform m transformations. The information he produces and how he chooses to transform it into knowledge is an expression of the individual researcher's own creativity, although he may be influenced by the people with

¹¹The concept of uncertainty in technology development is developed by many authors, including Arrow (1962) who states "Producers [of knowledge] have to make decisions on inputs at the present moment, but outputs are not completely predictable from the inputs." (p. 610) See also, Sahal (1983) who contends "We find...that technological progress is a cumulative process of learning to learn and unlearn in a *probabilistic* manner." (p. 216)

¹²The literature on technological development tends to treat information and knowledge as indistinguishable concepts. See, for example, Arrow (1962).

whom he collaborates. Not all transformations are successful in yielding a unit of useful knowledge. Note also, any given k might be obtained from different transformations, or from the same transformation implemented simultaneously, albeit independently, by different researchers. The probability that a particular transformation will yield a unit of knowledge, $p(m) = k$, cannot be determined *a priori*, but rather is learned over time as researchers generate information and perform transformations. Moreover, the relevance of any piece of information (in that it might form part of the transformation which yields k) cannot be determined *a priori*.

The rate of growth in knowledge ($\partial K/\partial t$) is a function of the number of diverse of transformations ($\sum m$) that are performed, subject to the available information ($\sum i$) and the amount of additional knowledge required for commercialization ($K_z = K_c - K_t$): that is, $\partial K/\partial t = f(\sum m \mid \sum i, K_z)$. It is expected that greater levels in the diversity of m will be associated with higher rates in the production of new units of knowledge. Moreover, the likelihood of success of any given transformation improves as the amount of information it draws on increases and as the amount of knowledge necessary for commercialization decreases.¹³

The research community, R , is said to be perfectly contiguous if for each r , $\sum i_1 = \sum i_2 = \sum i_3 \dots \sum i_n$; that is, information is symmetric. Conversely, R is perfectly non-contiguous if for each r , $\sum i_1 \neq \sum i_2 \neq \sum i_3 \dots \sum i_n$; that is, information is asymmetric. The degree of contiguity of R is influenced by the existence of organizational boundaries between researchers and their economic motivations. Organizational boundaries are important for two reasons: first they give rise to information asymmetries because they impede the flow of information and increase the cost of information gathering. As a result, organizational boundaries can slow the rate of production of k within a community by reducing the amount of information available to each researcher. However, organizational boundaries can also enhance the rate of k production to the extent it increases the

¹³This notion can be understood in terms of Kuhn's (1970) jig-saw puzzle analogy of science. At the start, the puzzle is quite difficult, but as pieces are linked together and the picture becomes more full, the ease in finding the next piece to fit increases.

diversity of m pursued by R as a whole, since researchers in different organizations are likely to have different information sets and use different transformations.

The communication impedance effect of organizational boundaries is overcome via researchers who act as technological gatekeepers--that is, researchers who tend to communicate with others in different organizations.¹⁴ Given the economically rational behavior of researchers, the communication of information across boundaries occurs as a form of *quid pro quo*.¹¹ Boundary-spanning communication is defined here in a restricted sense as person-to-person exchanges and does not include publications. (Papers are very limited mechanisms for information exchange because of the delay in publication, the problems in encoding complex information, and the inability to ensure fair exchanges. Published papers can serve as a mechanism, like patents, to stake claims to knowledge.)

(4) The researcher's objective is to maximize the number of units of k he produces and can lay claim to before other researchers. Each knowledge unit has potential value, but it is assumed that the ultimate value of the researcher's claims depends upon whether or not all problems necessary for reaching the point of commercialization are resolved and the length of time taken. That is, knowledge has value only when it is used, and the sooner it is used the greater value it will have. The researcher does not need to produce all the knowledge required to reach t_c ; it is inconsequential to him who solves the other problems, as long as his claims to one or more k are established.

The researcher's intellectual capital consists of two components: general disciplinary knowledge that is held in common with other researchers, and specialized knowledge that flows from his work related to a particular technology (Σk). It is assumed that the researcher can contribute to alternative technologies within the realm of his disciplinary knowledge, and that he is free to switch at any time.

¹⁴See Allen (1979).

Since his choice is guided by the objective to maximize Σk , the researcher is motivated to enter only those fields in which he believes the transformation process has a high probability of yielding him units of knowledge he can claim. The value of $p(m) = k$ is learned over time as the number of transformations researchers perform increases. Thus a researcher may be encouraged to enter a field he believes might have a high value of $p(m)$, but the actual probability can only be determined with experience. If $p(m)$ is equal to or greater than expected (i.e., the task of acquiring k is easier than anticipated), then the researcher will remain in the field; however, if $p(m)$ is lower than expected (i.e., acquiring k is harder than anticipated), then the researcher might switch to another field with higher perceived $p(m)$. The switching behavior of a researcher is moderated by the length of time he spends contributing to a technology's development and the amount of knowledge claims he accumulates. A researcher's specialized knowledge (Σk) becomes a sunk cost: the more k the researcher accumulates over time, the less likely he is to exit a field prior to t_c .

(5) At this point, it is possible to draw together the basic elements outlined above into a dynamic model of the process of technological development (see Figure 2).¹⁵ To begin, suppose that at the initiation of a new technology ($t = 1$), there are a certain number of researchers involved (R_1) who in each instant of time produce a certain amount of information (Σi) and perform a certain number of transformations (Σm). The researchers' effort yields a rate of growth in knowledge ($\partial K/\partial t > 0$) which, given the problem set confronting them, implies a rate of progress toward commercial introduction of the technology ($\partial t_m/\partial t$, where $t_m = t_c - t_1$). The resulting rate of progress, in turn, influences the decision of a researcher to enter, remain in or leave the community. Since the size of the research community determines how much information is produced and how many transformations are performed, the entry or exit decision of researchers is of critical importance to the acceleration or deceleration in the production of knowledge.

It is important to notice that the researcher's decision to enter or exit a field

¹⁵To be more precise, it may be possible to formulate a systems dynamic model of R&D communities. Although not presented here, one is currently under consideration. See Roberts (1981) for an overview of system dynamic modelling.

is not a one-time choice, but rather is subject to consideration over time. The attractiveness of developing a particular technology changes over time, as more information is produced and researchers learn the probabilities in transforming this information into knowledge. Its attractiveness also may be influenced by changes in other technologies, and indeed a variety of other events, all of which will be reflected in the researcher's decision.

Suppose, as time progresses, the degree of difficulty in transforming information into the required knowledge becomes more apparent and it is lower than expected. This will result in an acceleration in the rate of knowledge growth ($\partial^2 K / \partial t^2 > 0$) that implies a point of commercialization sooner than anticipated. Some researchers will respond to this change in conditions by entering into the field ($\partial R / \partial t > 0$), which will contribute to the production of information and transformation process and feed the acceleration further. Conversely, suppose the transformation process performed by researchers is proving more difficult than expected. This will result in a deceleration in the growth of knowledge ($\partial^2 K / \partial t^2 < 0$) and, consequently, the point of commercialization will be shifted further out into the future. This is a negative signal to potential entrants and may also lead to the exit of researchers from the field (subject to their sunk cost considerations mentioned above.) The effects of these changes are illustrated in Figure 3 and 4.

The impact of the flow of researchers into a field on $\partial K / \partial t$ is moderated by the burgeoning community's structure and behavior: that is, the contiguity of the community as determined by the distribution of researchers across organizations and the communication between them. To illustrate this point, assume the extreme conditions of perfect contiguity and perfect non-contiguity. In the first case, as the research community grows, all researchers are employed by the same organization. Thus all researchers are assumed to have the same information set, but the diversity of transformations performed is limited by the researchers' mutual influence. In the second case, as the community grows, each researcher is employed in a separate organization. Thus, each researcher is working from a different set of information and performing independent transformations, such that the diversity of transformations is maximized. Simply stated, in one situation each researcher in the community has a wealth of information but a limited number of approaches in

transforming that information into knowledge; in the other situation, although the community generates the same amount information, the amount available to any particular researcher is small and the variety of approaches taken is great.

STRATEGIC CONSIDERATIONS

Technology strategy has tended to focus on the firm and industry as the principal units of analysis. It is proposed here that the concept of an R&D community may have something to add to our understanding of technological development, and thus may prove useful in the strategic considerations of managers. This section will review the possible benefits of an R&D community perspective to technology strategy.

First, examination of the R&D community broadens attention from the analysis of firms in a particular industry (as define by its products), to all types of organizations in various types of industries and sectors of the economy. This more comprehensive perspective can be most critical in understanding the emergence of a new technology, since a whole new industry may form from the efforts of these disparate organizations. For example, in the case of the emergence of semiconductor technology, it lead to the formation of a new industry distinct from the industry based on the established technology (that is, vacuum tube manufacturers).¹⁶

Second, analysis of R&D communities may provide for better anticipation of emerging technologies. It is typical for emerging technologies to be in development for a decade or more prior to commercialization. Therefore, the evolution of the R&D community can precede the formation of an identifiable industry by many years. Strict focus on the industry may lead to chronic lags in a firm's technology development efforts.

Third, focusing on the R&D community may provide managers with insight into the structure of the social network among researchers and communication

¹⁶See Braun and Macdonald (1982).

flows. The evolving network structure may be an early signal to the formation of strategic alliances between firms as the technology approaches commercial introduction. Also, analysis of the network structure will enable the firm to determine whether or not it is adequately--as researchers say--"plugged-in to the grapevine." Where a firm sits in the network determines how much information is available to its researchers. The firm does not have to be a central node in the network, so long as it knows and interacts with those organizations which are the central nodes.

Fourth, the R&D community perspective highlights the collective action dimension of technological development, and in this way it addresses directly the strategic interdependence which may arise. Unless a researcher or a firm can produce all the necessary information and resultant knowledge required for commercialization of a technology, then the technology's development is ultimately a collective action problem where the decisions of researchers and firms are interdependent. Managers can view themselves in an adversarial position, where the object is to monopolize claims to all units of knowledge with respect to a particular technology; or managers can see themselves faced with a collective action problem, in which the goal is to establish some claims to knowledge while at the same time promoting the technology's development among other organizations so that all the necessary knowledge will be established.

The approach taken has implications for the return, rate of development, and risk facing the firm. In the first case, the return is relatively high, but the speed at which the technology develops may be slower and the risk of absolute failure in the effort great. In comparison, in the second case the return may be lower, but the rate of development faster and the risk of absolute failure less.

The well-known historical example that illustrates this concept is the development of semiconductor technology beginning with the transistor. After the invention of the point contact transistor at Bell Laboratories, AT&T pursued a strategy to promote development of the technology broadly holding symposia to transfer information and knowledge about the transistor to all other interested organizations, and offering low-royalty licenses on the transistor patent. The effect

on the growth of a semiconductor R&D community was noticeable, as many more organizations did become involved in developing the transistor. Indeed, many critical advancements in semiconductor technology necessary for commercialization of the technology came from researchers outside of Bell Laboratories, researchers who might not have taken part in the technology's development had it not been for AT&T's promotional efforts.

CONCLUSION

This paper proposes the idea that the "R&D community" is a useful concept in understanding the rate of a technology's development toward commercialization. An initial theoretical exposition is provided, and a brief discussion of the implications for technology strategy. Clearly much more research is required to fully understand the importance of this conception of technological development.

A research program focused on the study of R&D communities in technological development is currently in progress. This research seeks to identify and measure changes over time in the structural and behavioral characteristics of R&D communities and the relationship between these factors and the rate of progress achieved. Technologies under investigation include:

- GALLIUM ARSENIDE INTEGRATED CIRCUITS
- JOSEPHSON JUNCTION DEVICES
- REDUCED INSTRUCTION SET COMPUTERS
- NEURAL NETWORK COMPUTERS
- MAGNETIC BUBBLE MEMORY STORAGE DEVICES
- HIGH-TEMPERATURE SUPERCONDUCTING MATERIALS
- POLYPROPELENE PROCESS TECHNOLOGY
- EPDM RUBBER PROCESS TECHNOLOGY
- MICROGRAVITY MATERIALS PROCESSING

Although these studies are already yielding a wealth of information about R&D communities, further research is required for insight into why R&D communities

function as they do and to provide better a understanding of the implications for technology strategy.

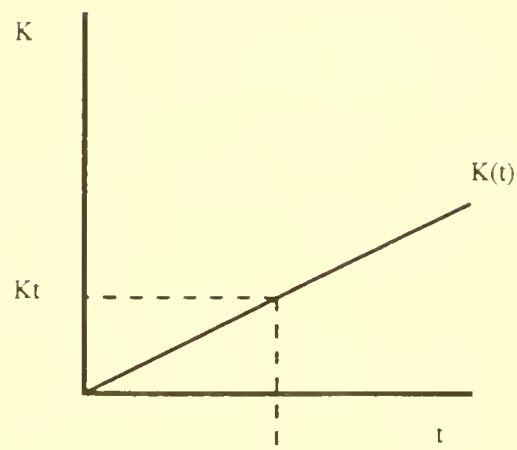
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FIGURE 1

(a)



(b)

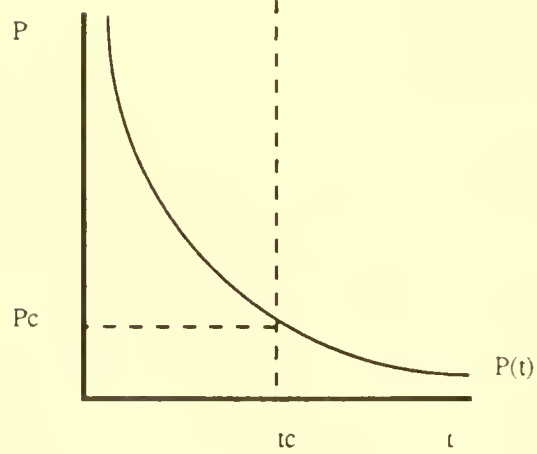


Figure 1. Theoretical curves of the relative concentration of the component i in the mixture as a function of the relative concentration of the component j in the mixture.

Figure 2. Theoretical curves of the relative concentration of the component i in the mixture as a function of the relative concentration of the component j in the mixture.

Figure 3. Theoretical curves of the relative concentration of the component i in the mixture as a function of the relative concentration of the component j in the mixture.

Figure 4

Figure 5. Theoretical curves of the relative concentration of the component i in the mixture as a function of the relative concentration of the component j in the mixture.

Figure 6. Theoretical curves of the relative concentration of the component i in the mixture as a function of the relative concentration of the component j in the mixture.

Figure 7. Theoretical curves of the relative concentration of the component i in the mixture as a function of the relative concentration of the component j in the mixture.

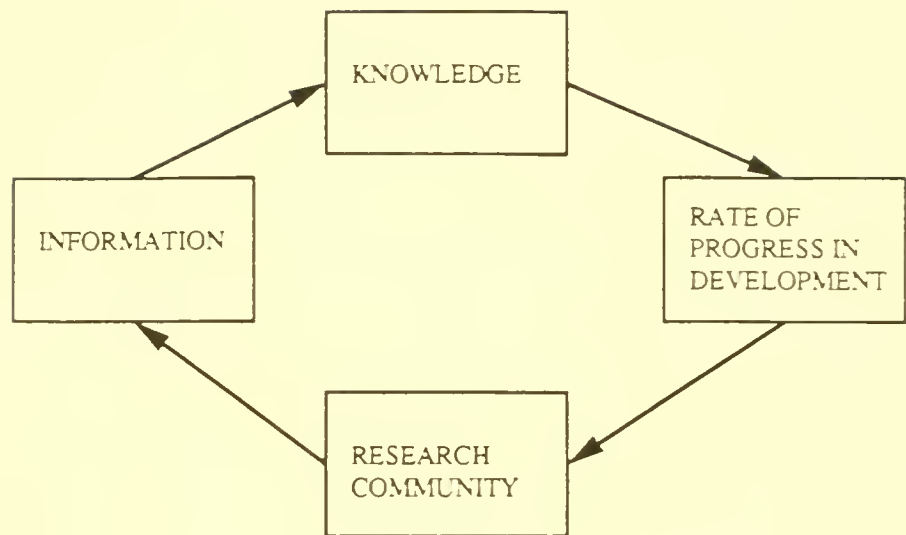
Figure 8. Theoretical curves of the relative concentration of the component i in the mixture as a function of the relative concentration of the component j in the mixture.

Figure 9. Theoretical curves of the relative concentration of the component i in the mixture as a function of the relative concentration of the component j in the mixture.

Figure 10. Theoretical curves of the relative concentration of the component i in the mixture as a function of the relative concentration of the component j in the mixture.



FIGURE 2



Diagram



FIGURE 3

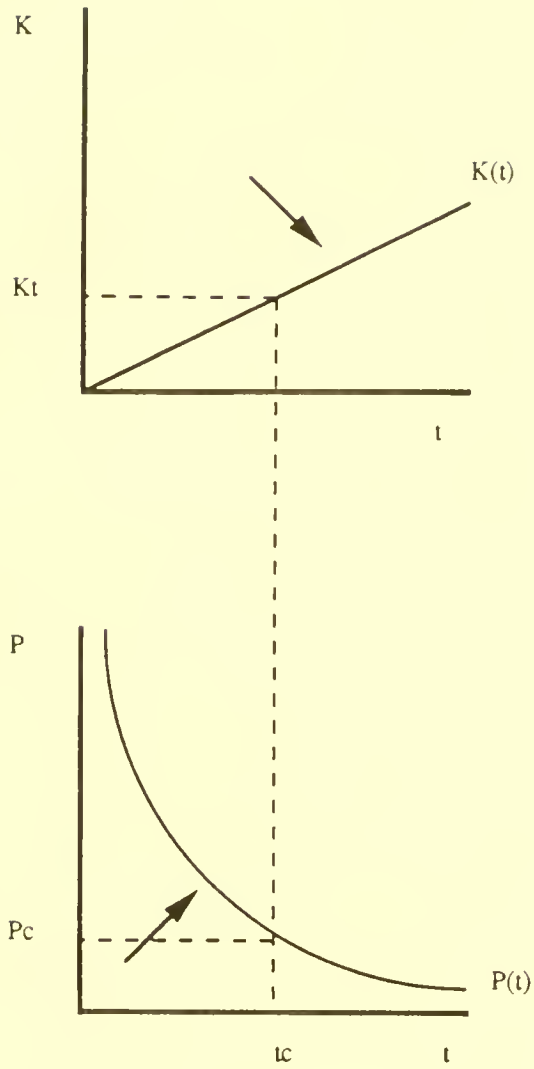
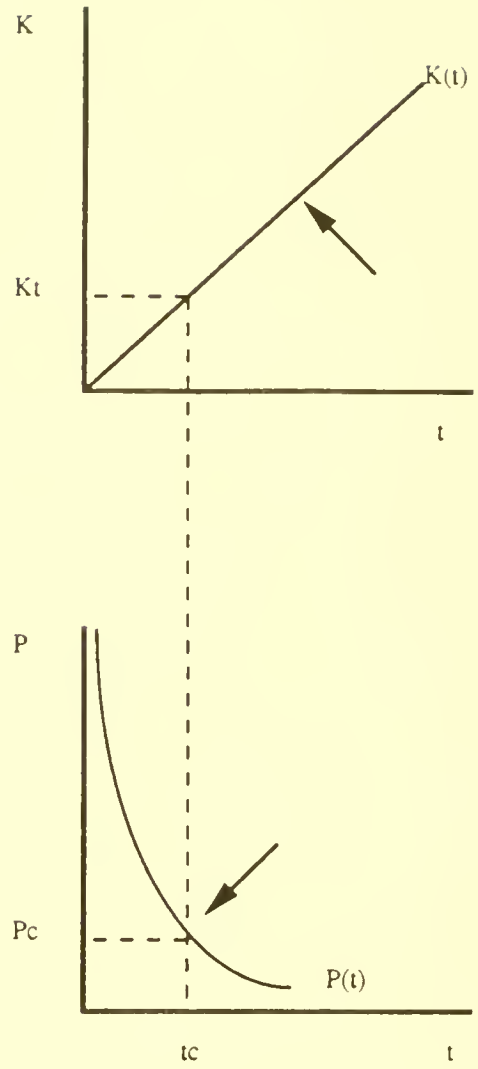


FIGURE 4



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